[한국식물병리학회 2003년 학술상 수상기념 특별강연 초록]

# Etiology and Epidemiology of Clubroot Disease of Chinese Cabbage and Its Management in Korea

**Choong-Hoe Kim**

Plant Pathology Division, Department of Crop Protection,
National Institute of Agricultural Science and Technology,
Suwon 441-707, Korea

Clubroot disease of curcifer crops caused by *Plasmodiophora brassicae* had been first reported in 1928 in Korea, and maintained mild occurrence until 1980s. Since 1990s the disease has become severe in alpine areas of Kyonggi and Kangwon, gradually spread to plain fields throughout the country, and remains as the greatest limiting factor for its production. Researches on the disease has begun in late 1990s in our laboratory after experiencing severe epidemics. Survey of occurrence and etiological and ecological studies have been carried out, particularly, on the pathogen physiology, race identification, quantification of soil pathogen population, host spectrum of the pathogen, and control measures.

In cropping systems chinese cabbage-monocropping or chinese cabbage-radish was found to be most common in major chinese cabbage production areas. Welsh onion, squash, or paddy rice was also planted between cropping of chinese cabbage. Paddy fields converted to upland were lower in incidence of clubroot disease. Soil pH and organic contents were not related to disease severity. Soil fauna, such as, total fungi, bacteria, actinomyces, Psedomonads and *Bacillus*, were not correlated with severity of the disease. Root gall development on chinese cabbage seedlings was initially observed under a microscope 13 days after inoculation with *P. brassicae* but 18 days by naked eyes after inoculation. Root galls were formed mostly around collar roots and gradually spread to main root, lateral roots and secondary root branches. Root galls started to enlarge greatly in size and weight from 23 days after inoculation. Chinese cabbage plants at mid-growth stage with root gall development were reduced to 1/2 of that of healthy plants in number of leaves, 1/4-1/5 in above ground fresh weight, 1/6 in root length, but increased to three times in diameter of collar root. Diseased plants had little root hairs. Diseased chinese cabbage at harvest was reduced by 9.1-11.8% in head weight compared to healthy plants, but increased by 2.8-5.7 times greater in root weight depending on the clubroot severity. In healthy plants, a positive correlation was observed between root and head weight, but those relationships were rot found in the diseased plants.

Development of root galls on chinese cabbage seedlings was first observed 17 days after inoculation of *P. brassicae*, at 25℃ 4-11 days earlier than at 5, 20, 30℃ and 35℃. Subsequent enlargement of root galls was also fastest at 25℃ and 20℃, but delayed at 15℃ and 30℃ or above. Root gall development was highest at soil moisture level of 80% of maximum soil moisture capacity than at 60% and 100%. Optimum soil pH for root gall development was pH 6, although root galls

were formed at a range of pH 5 to 8. Period of light illumination also affected root gall development with the greatest gall development at 12/12hr in light/dark period and the least at 8/16hr. Site of root gall formation and gall shape did not differ among treatments of temperature, soil moisture, pH and light experiments.

A total of 739 root galls of crucifers infected with *P. brassicae* were collected from 18 locations of six provinces in Korea. All the samples were tested for race grouping of the pathogen by artificial inoculation to four differential varieties of turnip and rutabaga. Out of 16 races possible, 14 races except race 10 and 12 were identified. Fourteen races were isolated from chinese cabbage, seven from radish, nine from cabbage, and five from turnip. Thirteen races were isolated from the samples collected from Haenam, Jeonnam province showing most diversity. Six hosts of the pathogen; chinese cabbage, radish, cabbage, turnip, brown mustard, and kale were found in Korea. The pathogen was also viirulent to shepherd's purse among weeds tested.

In the artificial inoculation tests root galls were developed at the concentration of $10^5$ resting spore or above per mℓ of inoculum, and as inoculum concentration became higher, rate of development of root galls was faster. In infected plants fresh weight of above ground parts was reduced to 30-44%, but root weight increased by 4-10 times. Growth of diseased plants was greatly retarded. Planting in the diseased soil, as one of inoculation methods, was most effective for disease development showing uniform infections. Time of initial root gall development was delayed by root soaking inoculation. Soil drenching method failed to infect all plants inoculated. However, root gall enlargement after its initial development did not differ with inoculation method. Sixteen-day-old seedlings were found to be most adequate for inoculation test.

Yield loss of chinese cabbage plants increased as the infection time becomes early. Plants infected at 20 days after transplanting or earlier were completely killed before harvest, and those infected at 30 days after transplanting were healthy in appearance, but their head weights were reduced to 59% with poor commodity value. The plants infected at 40 days after transplanting were not affected in yield. Development of root hairs in diseased plants was greatly reduced as disease progressed, and root length was reduced to 1/2 to 1/3 of that of healthy plants. Root galls were first observed in field 20 days after inoculation and rapidly enlarged to highest in size, 20 days from initial development, and decayed thereafter. Development and decay of root galls tended to be faster as season progressed, where temperature became higher, regardless of the infection time. Diseased plants started to wilt approximately 10 days after root gall development. Root galls began to decay 10 days after initial plant wilting, and then were completely rotten within following 10 days. Based on the results, root gall development stages of spring-sown chinese cabbage could be divided into 20 days of latent period, 20 days of root gall enlargement period, and 10 days of root gall decay period, followed by survival period in soil.

Population density of *P. brassicae* in soil from severely infected fields of chinese cabbage decreased as soil depth increased. More than 97% of total population was found in surface soil (0-5cm depth), and few resting spores of the pathogen were also detected in 40cm-deep soil. The pathogen was evenly distributed over the surface soil without clustering around chinese cabbage plants. Density of *P. brassicae* in soil at 23 chinese cabbage fields in Pyongchang, Kangwon province ranged widely from less than $10^4$ to above $10^6$resting spores/g soil. Few or none of *P.*

*brassicae* was found in virgin soil, intermediate with 0.36-2.75×$10^4$resting spores/g soil in fields of other crops, but more than 10 times higher population was found in severely infected chinese cabbage fields. Density of *P. brassicae* was highest in fields of monocropping of crucifers with some exceptions, but was low in rotated fields with corn, rye, medicinal crops or other non-host vegetables. Pathogen density in soil was decreased rapidly when rye or medicinal crops were rotated with chinese cabbage. An improved method for detecting resting spores of *P. brassicae* in soil was suggested in this study and seems to be adequate for estimating population density in soil in the aspects of clearer dyeing, increased detecting sensitivity, and simplicity in preparation.

Number of days required for complete decay of root galls was three days at 32℃ or higher, 12 days at 16~20℃ and 28 days at 8℃. As soil moisture level increased, root gall decay became faster resulting three days for complete decay under saturated moisture condition at high temperature of 32℃, and 8 days under the same moisture level at 24℃. Soil moisture effect on root gall decay was relatively low at 24℃ compared to 32℃. Stimulation of decay by soil flooding was not observed at 32℃ but apparent at 12℃. Influence of soil microflora on root gall decay was negligible. Based on these results, temperature appears to be the most important factor affecting root gall decay in soil. Root gall decay was affected more significantly by other environmental factors in low temperature conditions. Maturity of resting spores of *P. brassicae* in root galls tended to increase as root gall decay progressed. Density of the resting spores was lower in fresh root galls than decayed ones. Number of resting spores in completely decayed root gall was 6.5×$10^6$/g tissue and its maturity was over 95%.

Resting spore germination was the highest at 28℃ with 55.6 and 82.5%, 24 and 132hrs after incubation, respectively. Optimum pH for resting spore germination was pH 6, followed by pH 7 and pH 8, and the germination was inhibited at pH 4, and pH 9. Germination of resting spores was stimulated by root extracts of radish, chinese cabbage and kidney bean, but inhibited by that of lettuce. Number of inactive resting spores was increased as temperature increases and time prolongs after temperature treatment. However, degree of inactivation of resting spores after 1hr at 40 to 65 ℃ was similar with 40 to 60%, but rapidly increased to 91.5% at 70℃. When root galls were submerged in water, density of inactivated resting spores was increased rapidly and reached 60.3% nine days after flooding. Flooding of infested soil resulted in 30% reduction of survived resting spores five months later. Among the two fungicides registered, fluazinam was better for inactivation of resting spores than flusulfamide, but both fungicides were inferior to phosphoric acid in laboratory tests.

Five different crops, including astragalus, a resistant radish, welsh onion, shallot, and turnip, were planted for 1~2 years as a rotational crop for the control of clubroot disease of chinese cabbage in artificially infested experimental fields in Suwon, Icheon, and Yeonchon. Resistant radish and welsh onion showed more than 50% of mean control value compared to the continuous cultivation of chinese cabbage. Although astragalus had 46.9% in mean control value, the effect was unstable depending on time and place tested. Resistant radish reduced significantly pathogen population in soil, as well as welsh onion did. Resistant radish was more promising for rotational crop than welsh onion because of more efficient reduction of pathogen population in soil. Five moderate resistant cultivars of chinese cabbage, three resistant radish cultivars, and one moderate resistant cabbage

cultivar were selected for commercial recommendation, based on the results from three-year field tests in 1998 to 2000.

Cultural methods, including removing root galls from soil, and high ridge cultivation were ineffective to reduce the disease. Although lime amendment into soil did not show any disease reduction at the first year, some inhibitory effect was obtained by three-year consecutive amendment. However, excessive lime application caused physiological disorder of the plants. *Heteroconium chaetospira,* a root-parasiting endophyte, did not suppress the disease. Both fluazinam DP and WP showed some degree of control efficacy, but fluazinam had phytotoxicity to chinese cabbage. Dipping the seedling roots of chinese cabbage into fluazinam WP(2,000×) suspension showed a relatively high control efficacy without phytotoxicity. Combination of fluazinam WP dipping with seedling roots and flusulfamide DP mixing into field soil before transplanting resulted in the best in efficacy with consistency. Phosphoric acid was ineffective in field. Dazomet GR, a fumigant, was highly effective for the disease control. Solarization combined with fungicide application was effective especially in greenhouse cultivation. Among others, field soil mixing with flusulfamide DP combined with dipping of seedling roots in fluazinam WP was found to be most effective in the heavily infested fields. In the field with low inoculum density, fluazinam WP for dipping of seedling roots would be sufficient to inhibit the disease in fields.

In the future, more researches are needed to be done on development of resistant varieties effective to several races of the pathogen, establishment of economically-sound crop rotation system, and improvement of soil-disinfection technique applicable to Korean field condition, and development of methodology of pretreatment of fungicides onto seeds and seedbeds.

(E-mail : choonghoekim@rda.go.kr)